



US012226961B2

(12) **United States Patent**  
**Davidson et al.**

(10) **Patent No.:** **US 12,226,961 B2**  
(45) **Date of Patent:** **Feb. 18, 2025**

(54) **PREFORM CHARGES AND FIXTURES THEREFOR**

(71) Applicant: **Arris Composites Inc.**, Berkeley, CA (US)

(72) Inventors: **Erick Davidson**, Piedmont, CA (US); **Ethan Escowitz**, Berkeley, CA (US); **Riley Reese**, Carpinteria, CA (US); **Sean Hennessee**, San Francisco, CA (US); **J. Scott Perkins**, Berkeley, CA (US)

(73) Assignee: **Arris Composites Inc.**, Berkeley, CA (US)

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/600,131**

(22) Filed: **Oct. 11, 2019**

(65) **Prior Publication Data**

US 2020/0114596 A1 Apr. 16, 2020

**Related U.S. Application Data**

(60) Provisional application No. 62/744,822, filed on Oct. 12, 2018.

(51) **Int. Cl.**  
**B29C 70/46** (2006.01)  
**B29B 11/16** (2006.01)  
**B29C 65/00** (2006.01)  
**B29C 70/68** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **B29C 66/1122** (2013.01); **B29B 11/16** (2013.01); **B29C 70/46** (2013.01); **B29C 70/467** (2013.01); **B29C 70/68** (2013.01)

(58) **Field of Classification Search**

CPC ..... B29C 70/34; B29C 70/467  
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,414,125 A \* 1/1947 Rheinfrank, Jr. .... B29C 33/04  
428/111  
2,880,080 A \* 3/1959 Rankin ..... C08L 67/06  
51/297  
3,078,202 A \* 2/1963 Bellanca ..... B63B 5/24  
138/117  
3,138,507 A \* 6/1964 Wiltshire ..... B29D 22/00  
220/669

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0313155 A1 4/1989  
WO 2018/078501 A 5/2018  
WO 2020/236758 A1 11/2020

OTHER PUBLICATIONS

Authorized Officer Monika Schmitz, International Search Report mailed Jan. 20, 2020 issued in related PCT Application No. PCT/US2019/055951.

(Continued)

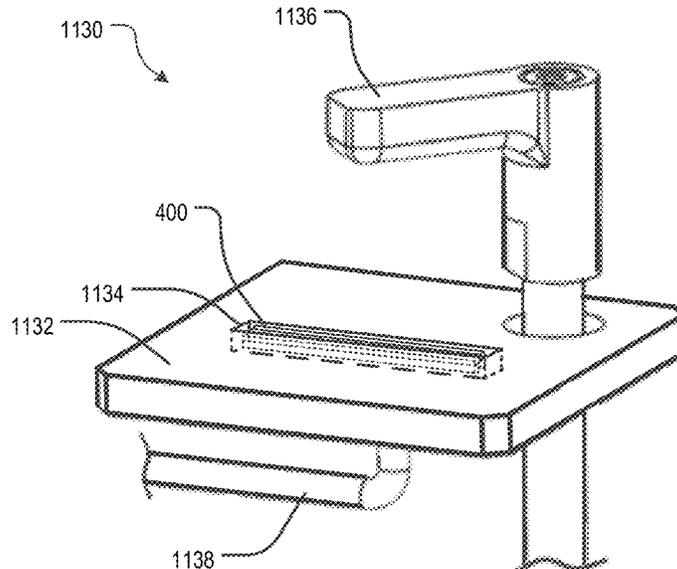
*Primary Examiner* — Andrew D Graham

(74) *Attorney, Agent, or Firm* — Kaplan Breyer Schwarz, LLP

(57) **ABSTRACT**

A preform charge is formed by forming an assemblage of preforms, wherein preforms in the assemblage are bonded to a neighboring preform such that the preform charge effectively becomes a single unit. The preform charge can then be added to a mold to fabricate a part via compression molding.

**16 Claims, 15 Drawing Sheets**



(56)	References Cited	7,846,366 B2 *	12/2010	Lobst	B29C 43/14
	U.S. PATENT DOCUMENTS	8,802,232 B2 *	8/2014	Adzima	D06M 23/08
3,150,032 A *	9/1964 Rubenstein B29C 70/086	8,993,084 B2 *	3/2015	Griess	B32B 5/26
	428/313.7				428/60
3,271,917 A *	9/1966 Rubenstein E04C 3/29	2002/0155251 A1 *	10/2002	Renault	B29C 43/203
	52/309.17				428/99
3,641,230 A *	2/1972 Jenks B29C 70/08	2003/0001376 A1 *	1/2003	Verhaeghe	B29C 53/086
	264/152				280/781
3,655,321 A *	4/1972 Wolf B29B 15/125	2003/0054150 A1 *	3/2003	Evans	B29B 15/105
	425/395				428/297.4
3,889,348 A *	6/1975 Lemelson B21F 17/00	2003/0104738 A1 *	6/2003	Porter	B29C 66/721
	419/8				442/134
4,339,490 A *	7/1982 Yoshioka B29C 70/00	2003/0155066 A1 *	8/2003	Roehr	B29C 66/54
	428/213				156/245
4,340,562 A *	7/1982 Gross B29C 33/0077	2003/0168164 A1 *	9/2003	Blackmore	B28B 11/24
	264/328.16				156/308.2
4,474,635 A *	10/1984 Adams B29C 44/10	2006/0073319 A1 *	4/2006	Roberson	B27N 3/002
	156/245				428/292.1
4,526,735 A *	7/1985 Norota D01D 4/02	2006/0172636 A1 *	8/2006	Bech	B29B 11/16
	264/450				442/1
4,804,427 A *	2/1989 Paul B29C 70/50	2006/0175731 A1 *	8/2006	Bech	B29C 66/1162
	156/180				264/259
4,853,868 A	8/1989 Medwin	2007/0020431 A1 *	1/2007	Nowacki	B29B 11/16
4,935,279 A *	6/1990 Perko B29C 70/38				428/102
	40/615	2007/0243368 A1 *	10/2007	Edwards	B29C 70/081
5,066,536 A *	11/1991 Cogswell B29C 66/721				428/292.1
	428/216	2008/0063864 A1 *	3/2008	Aisenbrey	B29B 9/14
5,076,601 A *	12/1991 Duplessis B29C 70/342				428/364
	264/258	2008/0099131 A1 *	5/2008	Umeda	B29C 66/524
5,080,385 A *	1/1992 Duplessis B29C 70/342				156/201
	264/258	2008/0260954 A1 *	10/2008	Paton	B29B 11/16
5,094,883 A *	3/1992 Muzzy B29C 70/50				427/385.5
	264/131	2009/0169833 A1 *	7/2009	Koon	B29C 70/30
5,152,856 A *	10/1992 Thein B29C 44/08				428/195.1
	156/245	2010/0092770 A1 *	4/2010	Wadahara	B29C 43/003
5,198,281 A *	3/1993 Muzzy D06M 23/08				428/339
	156/308.2	2010/0121463 A1 *	5/2010	Tormala	A61L 27/446
5,294,461 A *	3/1994 Ishida B29B 9/14				623/23.75
	156/166	2010/0136278 A1 *	6/2010	Cadd	B29C 63/0021
5,296,064 A *	3/1994 Muzzy B29C 70/20				428/60
	156/166	2010/0143145 A1	6/2010	Jones	
5,298,318 A *	3/1994 Soules C08J 5/10	2010/0178495 A1 *	7/2010	Taketa	B29C 70/14
	428/902				428/339
5,350,556 A *	9/1994 Abe B29C 66/73921	2010/0196637 A1 *	8/2010	Lippert	B29C 70/345
	264/248				428/36.1
5,401,154 A *	3/1995 Sargent B29B 11/10	2011/0136602 A1 *	6/2011	Hsu	B29C 70/68
	425/114				473/535
5,405,683 A *	4/1995 Sandusky B29C 70/20	2011/0156305 A1 *	6/2011	Lonsdorfer	B29C 70/443
	428/102				264/261
5,503,887 A *	4/1996 Diaz B29C 70/882	2012/0046136 A1 *	2/2012	Allen	A63B 60/16
	156/152				473/563
5,556,496 A *	9/1996 Sumerak B29C 70/525	2012/0269999 A1	10/2012	Kind et al.	
	156/166	2012/0302118 A1 *	11/2012	Kasuya	B29C 43/203
5,573,813 A *	11/1996 Custer B29B 15/122				442/304
	118/423	2013/0065714 A1 *	3/2013	Avnery	B29C 43/021
5,597,629 A *	1/1997 Johnson E04H 12/02				473/561
	428/102	2013/0082416 A1 *	4/2013	Wakeman	B29C 33/14
5,648,941 A *	7/1997 King B06B 1/0681				264/259
	367/176	2013/0134621 A1 *	5/2013	Tsotsis	B29B 11/16
5,667,881 A *	9/1997 Rasmussen B29C 66/72141				264/177.2
	442/179	2013/0189482 A1 *	7/2013	Dequine	B29C 43/52
5,753,164 A *	5/1998 Ritchie B29C 31/08				428/130
	264/102	2013/0309465 A1 *	11/2013	Oda	B32B 7/02
5,888,608 A *	3/1999 Tsai E04C 2/427				428/212
	428/105	2013/0330553 A1 *	12/2013	Johnson	B29C 66/1122
5,895,622 A *	4/1999 Ramani B05D 1/045				156/166
	118/308	2013/0334734 A1 *	12/2013	Takahashi	B29C 70/467
5,989,710 A *	11/1999 Matsuo B29B 9/14				264/257
	428/369	2014/0003955 A1 *	1/2014	Richter	B29C 70/547
6,331,028 B1 *	12/2001 O'Neill C08G 18/6674				416/230
	296/100.01	2014/0051310 A1 *	2/2014	Kunal	B32B 5/02
7,243,055 B2 *	7/2007 Chen B29C 70/30				442/1
	345/420	2014/0079908 A1 *	3/2014	Kato	B32B 3/06
					428/140

(56)

References Cited

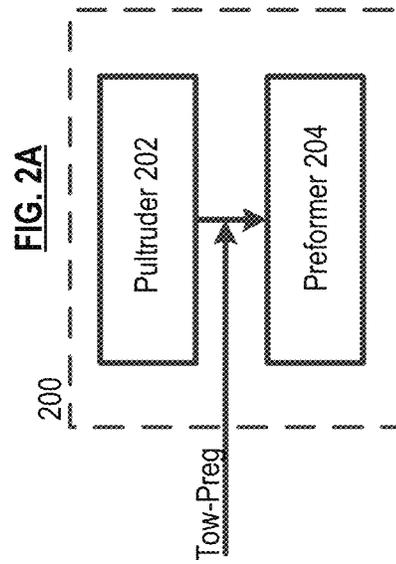
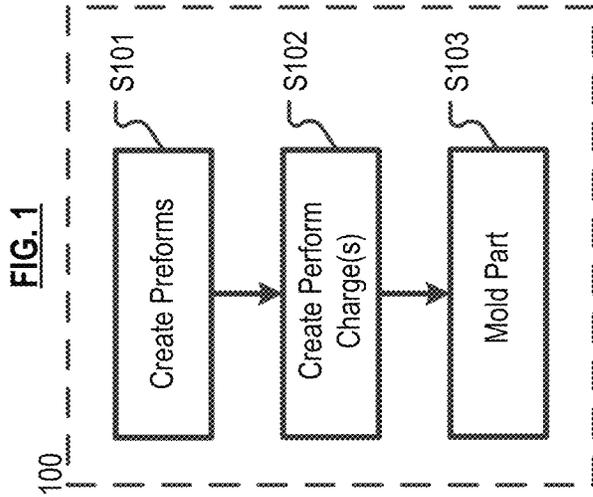
U.S. PATENT DOCUMENTS

2014/0178662	A1*	6/2014	Luo	.....	B32B 5/12 428/220
2014/0224410	A1*	8/2014	Millar	.....	F16B 39/22 156/92
2014/0265043	A1*	9/2014	Oldroyd	.....	B29C 41/085 264/482
2014/0272417	A1*	9/2014	Zeidan	.....	B29C 48/287 428/407
2014/0319879	A1*	10/2014	Reese	.....	B29C 70/32 296/193.02
2014/0323004	A1*	10/2014	Mihara	.....	B60R 13/02 442/311
2014/0361460	A1*	12/2014	Mark	.....	B29C 70/521 264/248
2015/0017853	A1*	1/2015	Perillat-Collomb	.....	B29C 70/467 442/1
2015/0044419	A1*	2/2015	Carson, Jr.	.....	A47C 5/12 428/138
2015/0151495	A1*	6/2015	Fisher, Jr.	.....	B29B 11/12 264/328.16
2015/0239209	A1*	8/2015	Newton	.....	B32B 5/26 428/113
2015/0298443	A1*	10/2015	Hundley	.....	B32B 38/1866 156/214
2015/0316027	A1*	11/2015	Sandercock	.....	B29C 70/52 416/230
2016/0114537	A1*	4/2016	Aubele	.....	B32B 37/10 156/173
2016/0136870	A1*	5/2016	Thienel	.....	B29C 51/12 428/213
2016/0339611	A1*	11/2016	Bartel	.....	B29C 43/18
2016/0355651	A1*	12/2016	Inoue	.....	B32B 5/022
2017/0103826	A1*	4/2017	Al-Harhi	.....	H01B 1/04
2017/0120519	A1	5/2017	Mark	.....	
2017/0173868	A1	6/2017	Mark	.....	
2017/0182729	A1*	6/2017	Fox	.....	B32B 3/08
2017/0210035	A1*	7/2017	Fan	.....	B29C 33/301
2017/0225383	A1*	8/2017	Taneda	.....	B29C 51/12
2017/0232674	A1*	8/2017	Mark	.....	B29C 31/042 264/308
2017/0254017	A1*	9/2017	Bertelo	.....	C08L 29/12
2017/0320278	A1*	11/2017	Meeks	.....	B29C 43/18
2017/0368812	A1*	12/2017	Palmieri	.....	B32B 27/38
2018/0030924	A1*	2/2018	Coppola	.....	F02F 7/0085
2018/0036970	A1*	2/2018	Chmielewski	.....	B29C 70/52
2018/0186101	A1*	7/2018	Ikeda	.....	B32B 5/26
2018/0222131	A1*	8/2018	Ducrot	.....	B29C 70/462
2019/0160715	A1*	5/2019	Mitsunaga	.....	B32B 27/12
2019/0177887	A1*	6/2019	Motohashi	.....	C08J 5/06
2019/0210303	A1*	7/2019	Jones	.....	B29C 70/345

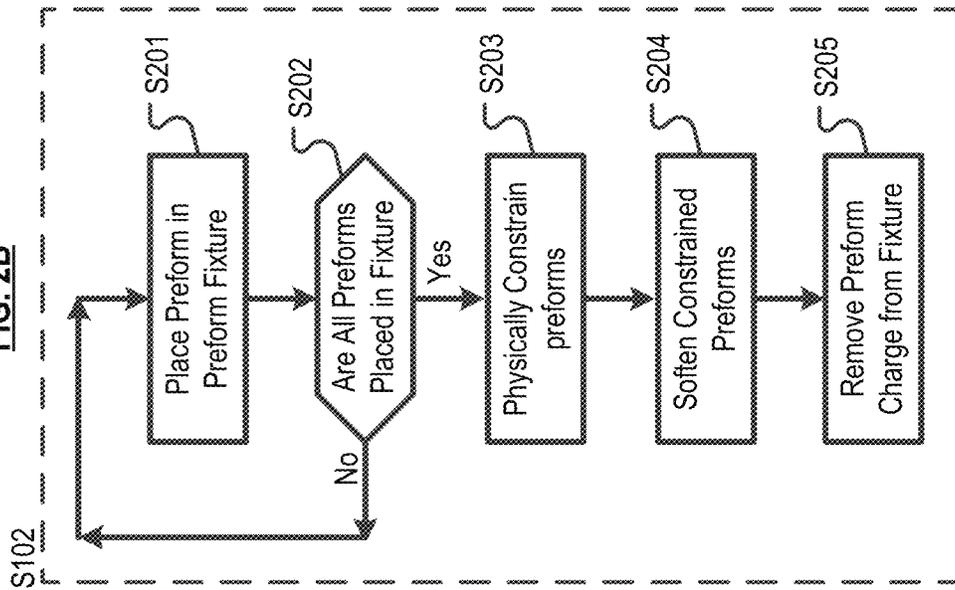
OTHER PUBLICATIONS

Lennart Wedhorn et al., "Quilted Stratum Process for High-performance CFRP Production", *Lightweight Design Worldwide*, Mar. 1, 2017, pp. 50-55, vol. 10, No. 1.  
 Non-Final Rejection Mailed on May 25, 2022 for U.S. Appl. No. 17/694,419.  
 Final Rejection Mailed on Sep. 14, 2022 for U.S. Appl. No. 17/694,419.  
 Office Action issued in European patent application No. 19795423.3, Feb. 21, 2023, 7 pp.

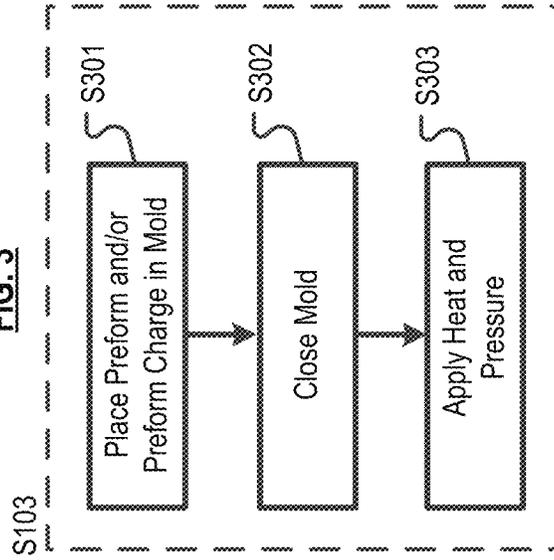
\* cited by examiner



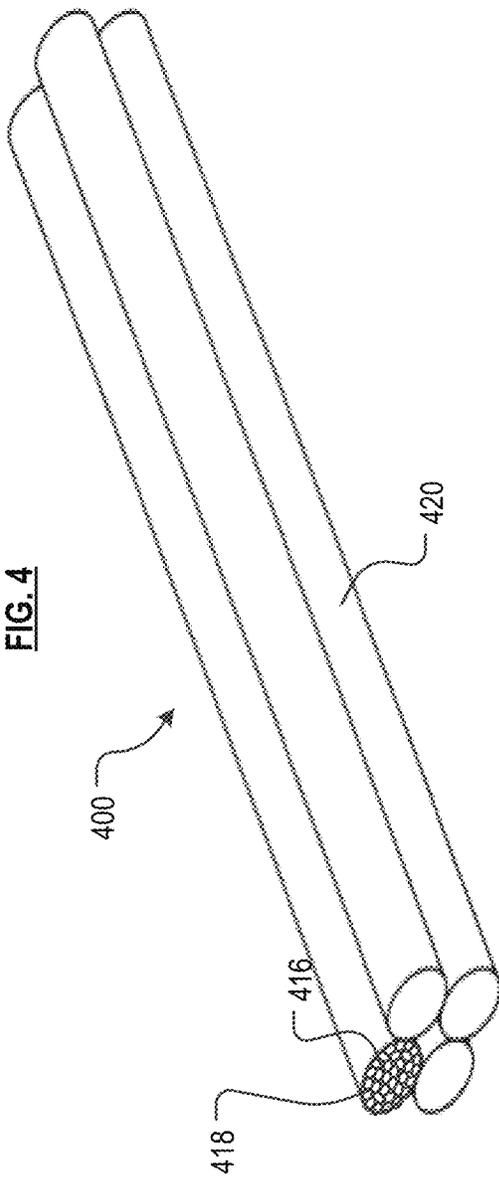
**FIG. 2B**



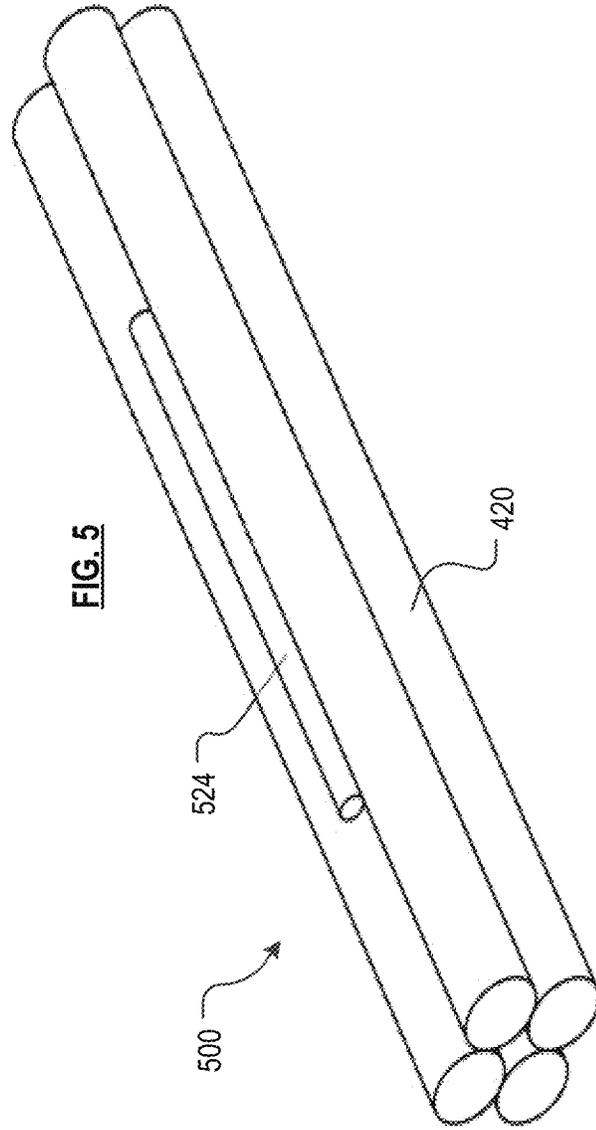
**FIG. 3**

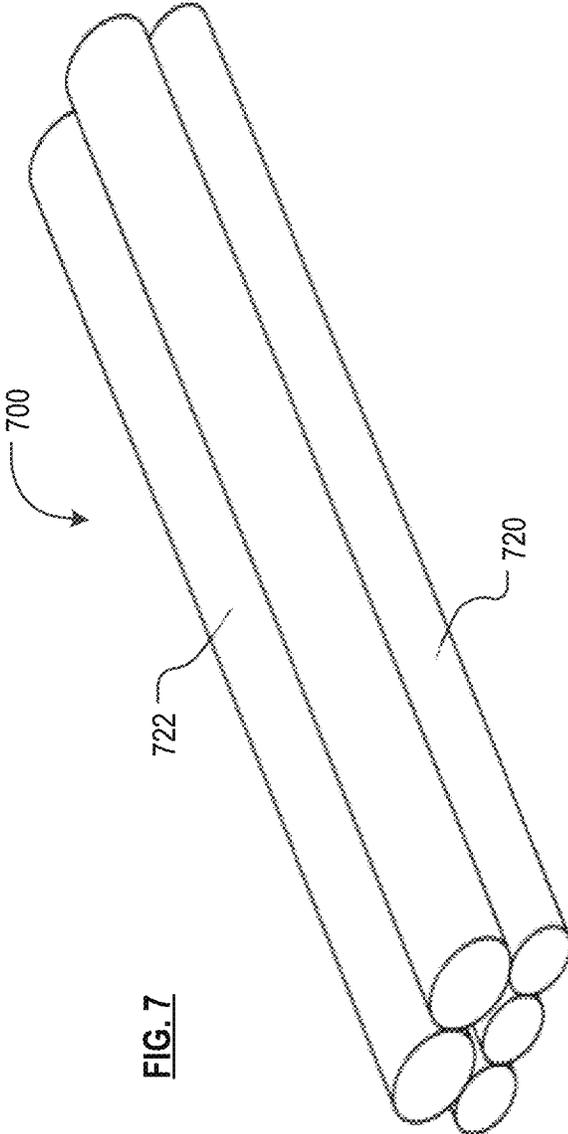
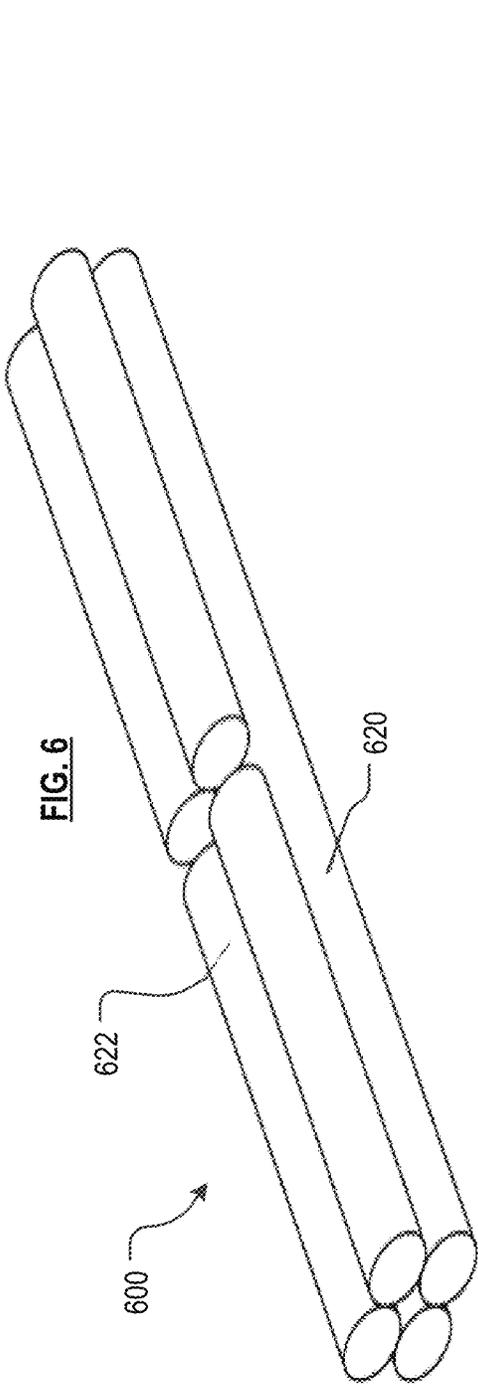


**FIG. 4**

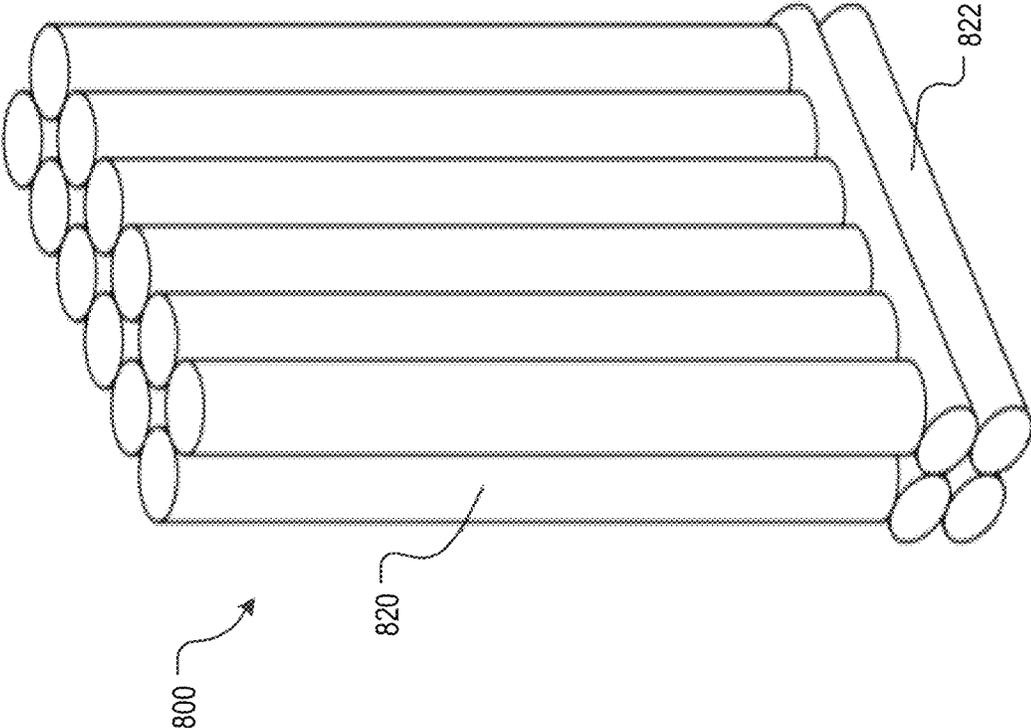


**FIG. 5**

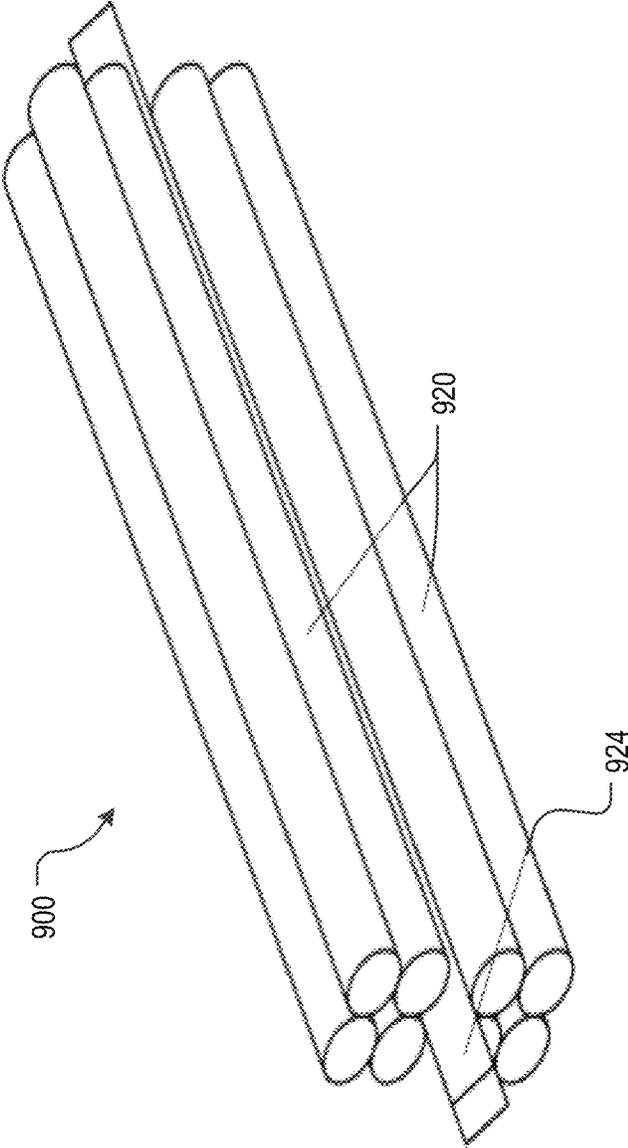


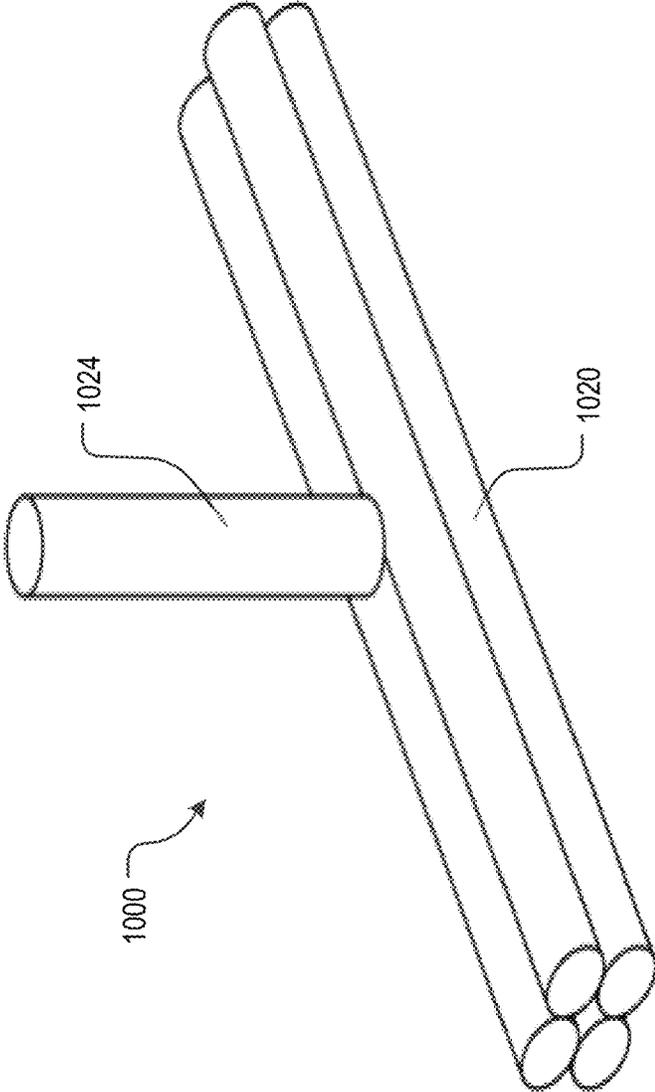


**FIG. 8**



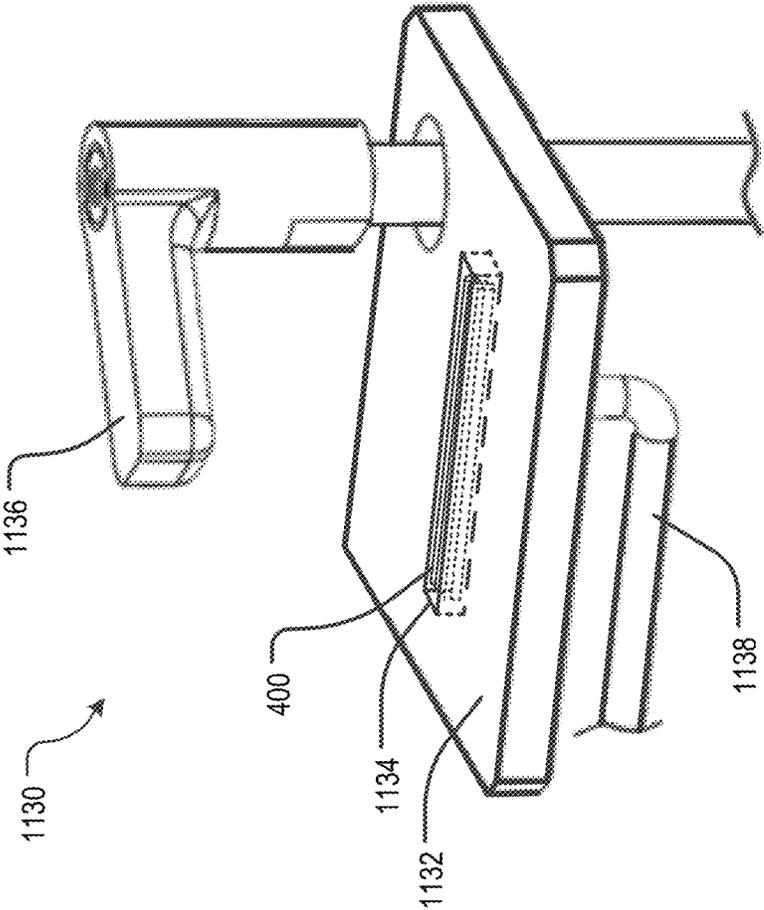
**FIG. 9**



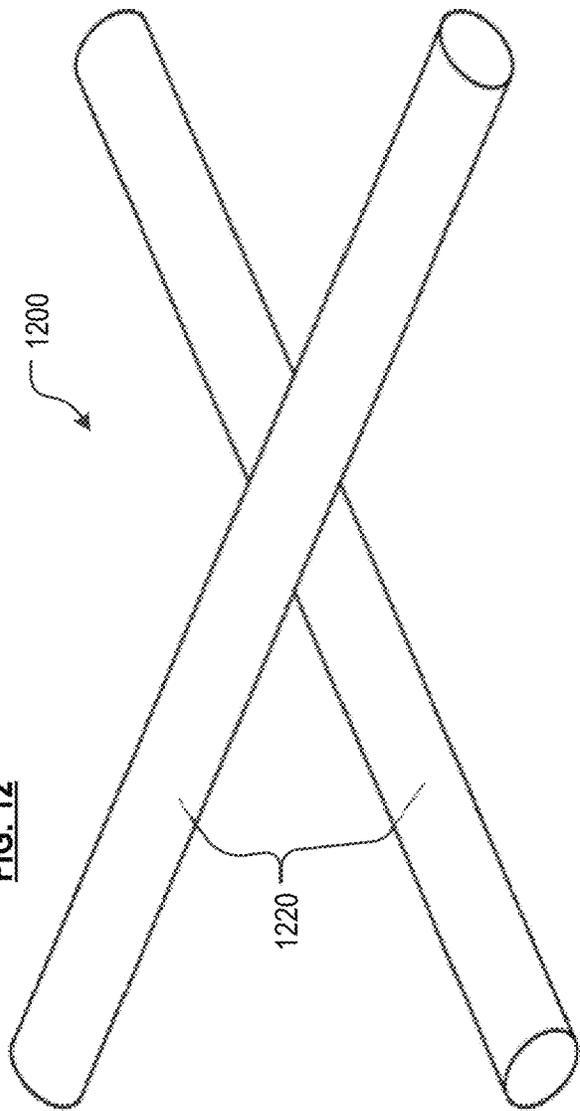


**FIG. 10**

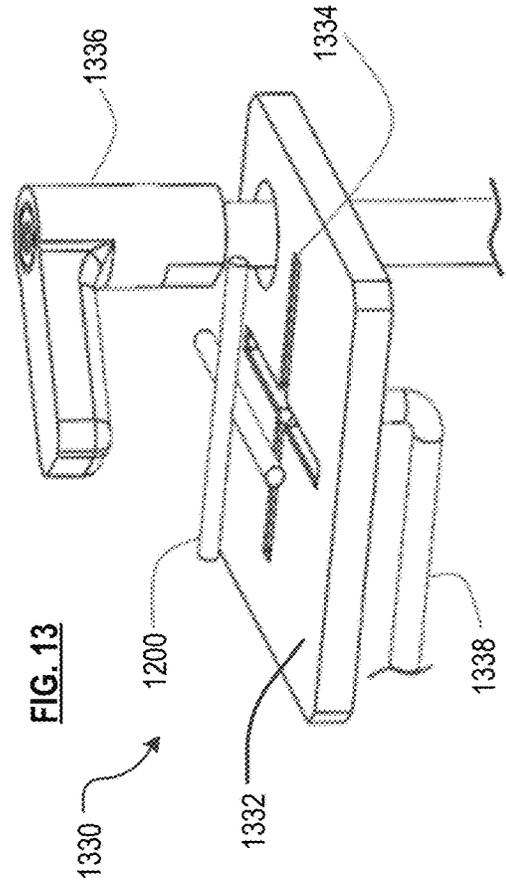
**FIG. 11**



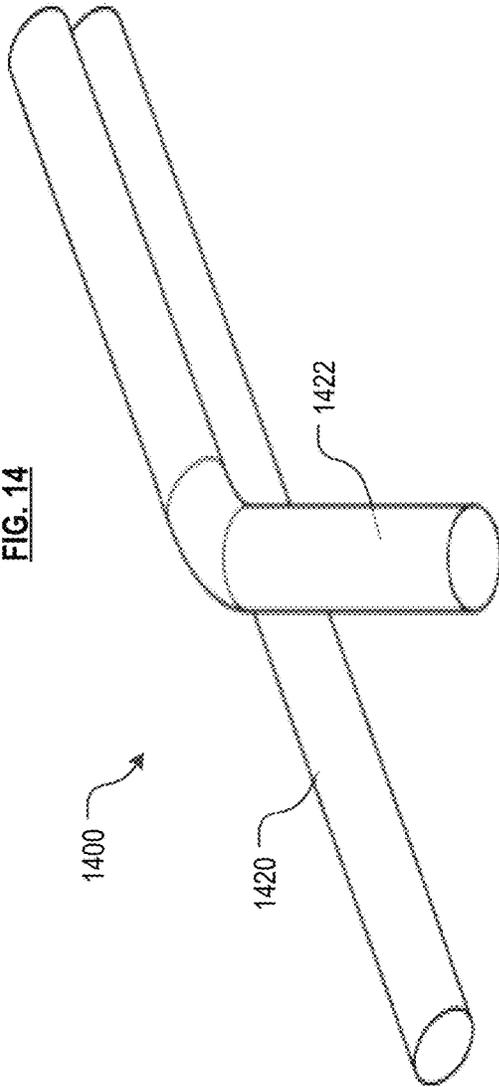
**FIG. 12**



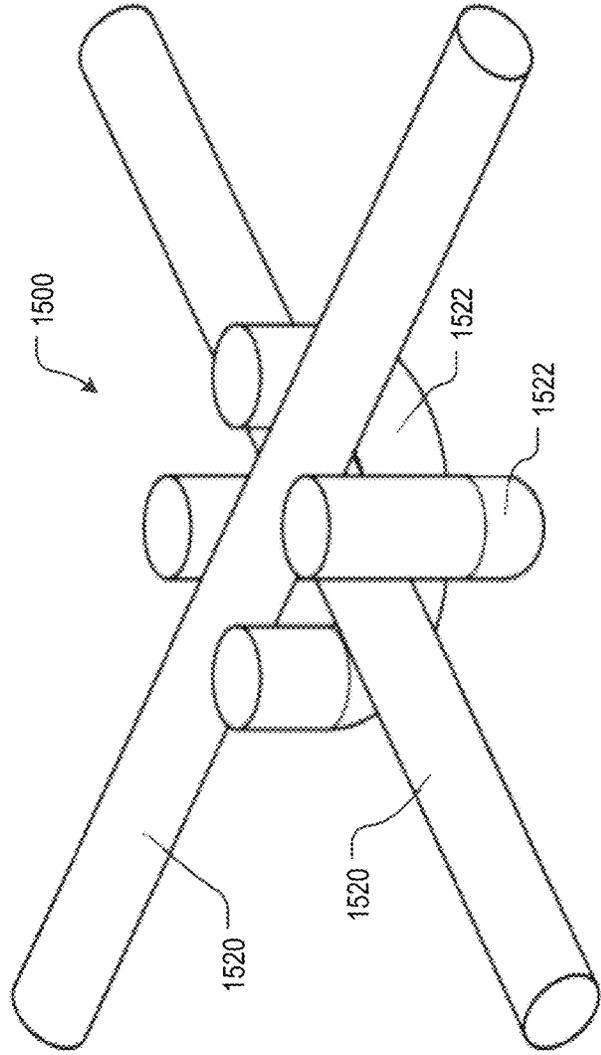
**FIG. 13**



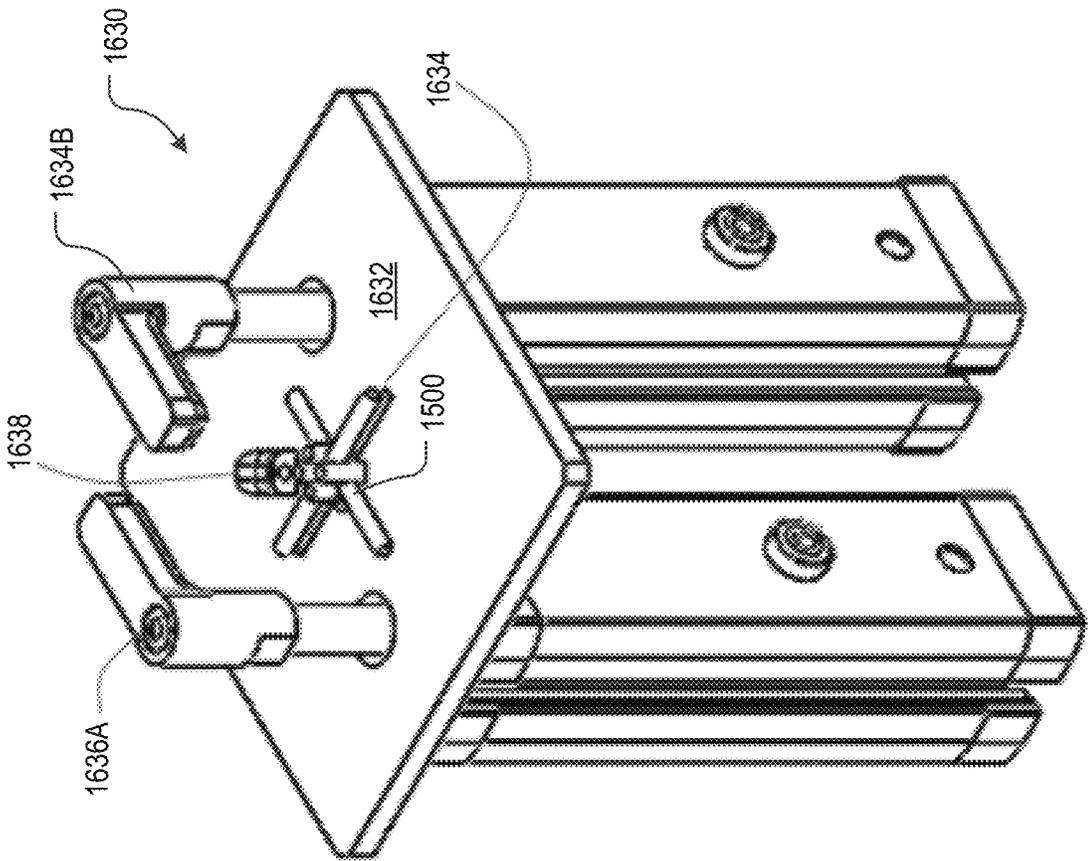
**FIG. 14**



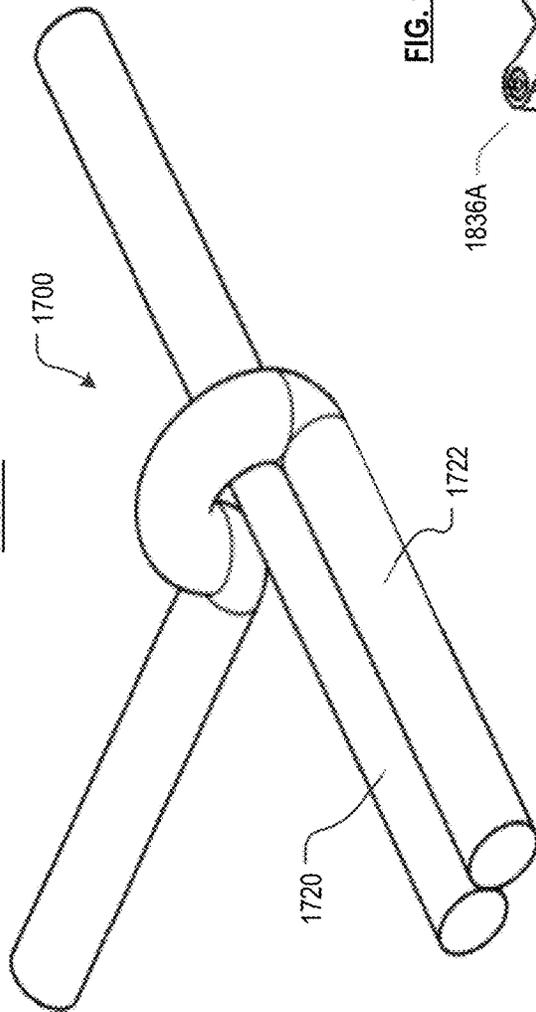
**FIG. 15**



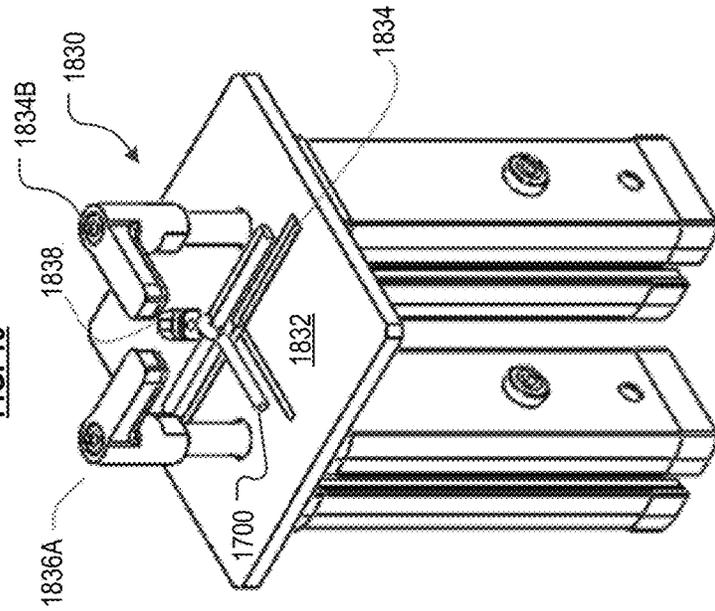
**FIG. 16**



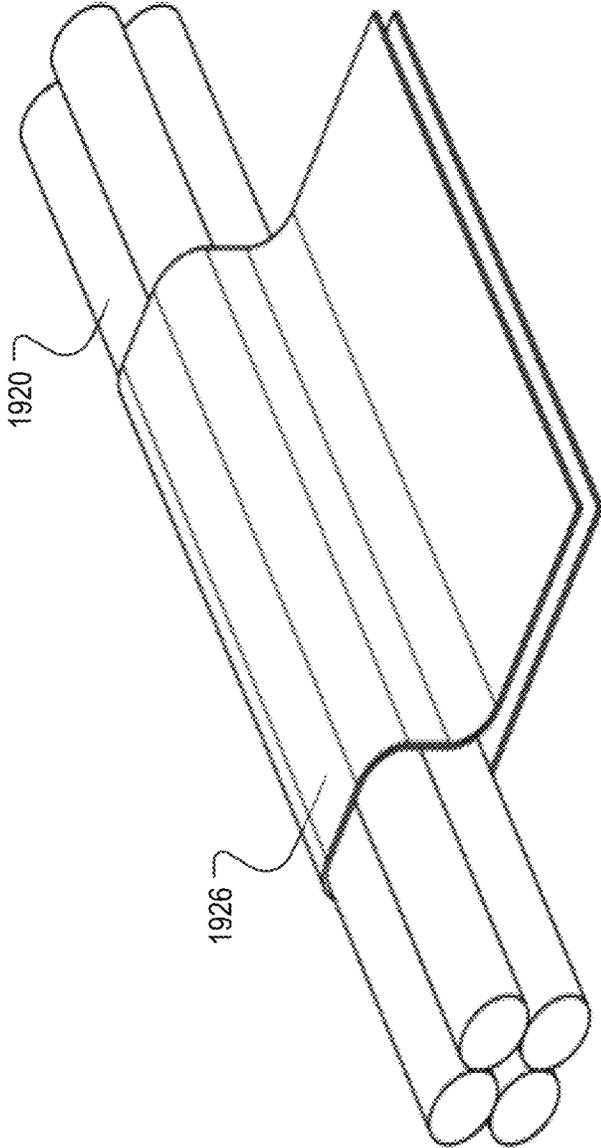
**FIG. 17**



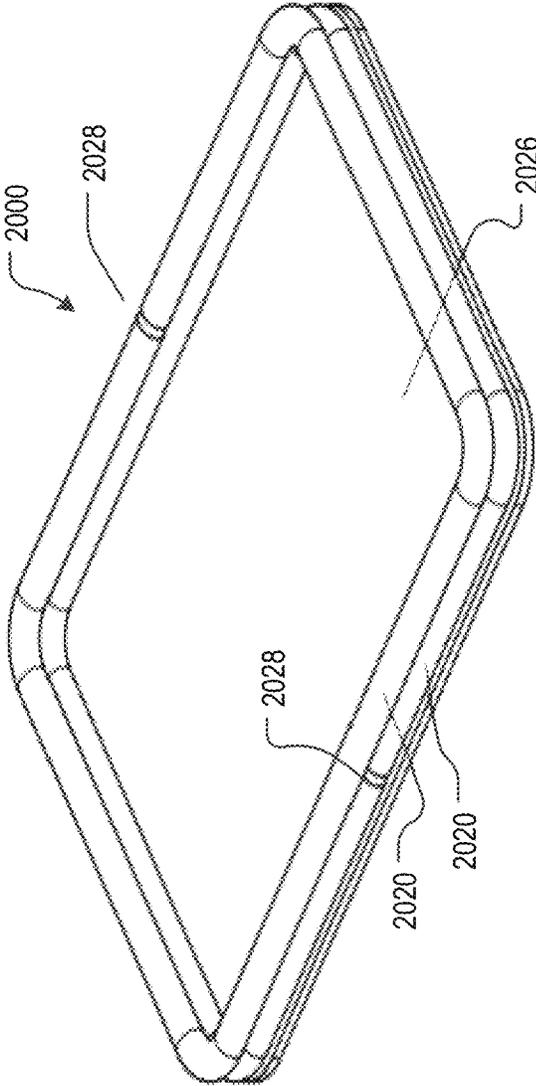
**FIG. 18**



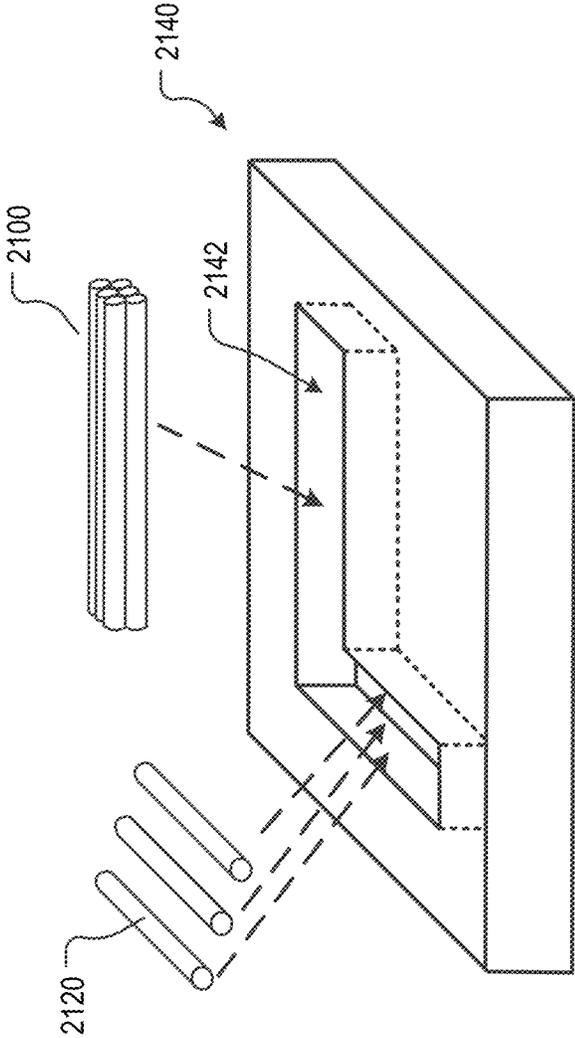
**FIG. 19**



**FIG. 20**



**FIG. 21**



## PREFORM CHARGES AND FIXTURES THEREFOR

### STATEMENT OF RELATED CASES

This case claims priority of U.S. Pat. App. Ser. No. 62/744,822 filed Oct. 12, 2018, which is incorporated by reference herein.

### FIELD OF THE INVENTION

The present invention relates to the manufacture of fiber-composite parts.

### BACKGROUND

There is a demand for high-volume, low-cost components (“parts”) that are made of fiber-composite materials, due to the superior material attributes (e.g., high strength, high stiffness, low mass, etc.) thereof.

Fiber composites include two primary components: a matrix material and a fibrous material. The fibrous material—fibers—are typically responsible for the strength of the composite, in addition to any other properties they contribute. The matrix, formed from a polymer resin, surrounds and supports the fibers, maintaining their relative positions and preventing abrasion and environmental attack thereof. The combination of the fibers and resin is synergistic, with the resulting properties depending on the specific fiber, resin, and fiber volume fraction.

The alignment of fibers within composites along directions of principal stress is an important consideration in deriving the maximum performance for a composite part. Current methods for manufacturing composite parts, especially in large quantities, are ill-suited for producing parts with aligned fibers. That is the case for all molding processes, including, for example, compression molding.

In the context of compression molding, one approach for filling the female mold involves lay-up of sheets of material. In a traditional lay-up process, multiple sheets of sized, unidirectional or bidirectional fabric (i.e., a weave) are placed on one on top of another in the mold. The sheets can be rotated relative to one another, such that sheets are oriented at, for example, 0°, +30°, -30°, etc. In another lay-up technique for compression molding, sheets of unidirectional or bidirectional fiber material are cut to an appropriate size and shape (e.g., a circle, semi-circle, rectangle, etc.), creating “preforms,” which are then placed in a compression mold. Since it is not possible to align fibers independently of one another within a sheet of material (fiber alignment in a sheet is fixed), these two methods at best provide a very limited ability to obtain a desired fiber alignment. This is particularly true with respect to discrete regions of a part. Furthermore, such lay-up techniques are very labor intensive and therefore quite costly.

In yet another technique, a length of unidirectional tape, functioning as a local stiffener, is placed in a mold along with chopped fiber (which necessarily has a completely random orientation). This technique can provide additional strength in a particular region of the part.

The art would therefore benefit from a way to efficiently and cost effectively produce high-volume, fiber-composite parts wherein the fibers can be reliably aligned in a mold with much greater freedom than in the prior art for best part performance.

## SUMMARY

The present invention provides a way to speed the production of high-volume, fiber-composite parts having fibers aligned, as desired, to an extent not possible in the prior art.

Applicant has been developing improvements to the compression molding process, among other molding processes. In accordance with an embodiment of the invention, constituent elements are placed in mold that produces a part via a compression-molding process. In some embodiments, the constituent elements are preforms, in some other embodiments, the constituent elements are preform charges, and in some further embodiments, the constituent elements are both preforms and preform charges.

A preform is a sized, or sized and shaped fiber bundle impregnated with resin. In the illustrative embodiment, the fiber bundle contains thousands of fibers, and is typically referred to as “tow.” In embodiments in which the fiber feedstock is tow, then the fibers in the fiber bundle must be impregnated with resin, such as via a pultrusion process. In some other embodiments, the fiber feedstock has already been impregnated with resin; such a material is typically referred to as “towpreg” or “prepreg tow.” For simplicity, the resin impregnated fiber bundle, however produced, is referred to herein as “towpreg.”

Thus, towpreg is sized (cut) so that it can fit into the mold. In some embodiments, sized towpreg is also bent into a desired shape, such as to fit a contour of the mold, or position the fibers of the sized towpreg in certain discrete regions of the mold. Again, such sized, or sized and shaped towpreg is referred to herein a preform. As used herein, the term “preform” does not refer to sized, or sized and shaped tape, sheets, or laminates.

Adding preforms, one-by-one, to a mold provides an ability to tailor, with great specificity, fiber alignment within a mold. Despite the flexibility in fiber alignment offered by the use of preforms, there are some drawbacks associated with such a technique. Consider that the bending machine that creates the preforms is likely to be some significant distance from the location of the mold. Thus, placing individual preforms in the mold until the requisite amount thereof have been added requires repeated trips from the bending machine to the mold. This is a time-consuming process. Furthermore, after placement in a mold, individual preforms may move out of their desired position/alignment. And once the mold is closed, it is typically not possible to determine if such movement has occurred.

In accordance with some embodiments, a “preform charge” is formed by tacking together plural preforms, wherein the preform charge effectively becomes a single unit. In embodiments in which the resin used (in the towpreg) is a thermoplastic, the preforms are tacked together by abutting them to one another (under minimal pressure) and heating them until they soften, followed by cooling. The temperature to which the bundles are heated is a function of the resin being used; it is within the capabilities of those skilled in the art to select a temperature for tacking as a function of resin type. Pre-cured thermosets, on the other hand, are tacky without heating. Thus, in cases in which the resin is a thermoset, fiber bundles can be pressed together with enough force to cause them to stick to one another.

The preform charge can be assembled at or near the bending machine, or at an intermediate location between the bending machine and the mold.

In some embodiments, a preform charge can include, in addition to preforms (i.e., sized or sized and shaped towpreg), fiber in other form factors, such as tape, sheets or

laminate. In some embodiments, a preform charge can include non-fiber inserts that are not intended to remain in a part being fabricated, such as to create through-holes in the preform charge. In yet some further embodiments, a preform charge can include inserts that are intended to remain in the part being fabricated, and can include threaded inserts, metal rods and active components, such as, without limitation, mechanical, electrical, optical, and piezoelectric components, and the like.

The properties of a fiber-composite part are a function of, among any other parameters, the type, geometry, and relative orientation of its constituent materials. Creating preforms or preform charges in accordance with the present invention provides an ability to manipulate the constituent molding materials in a manner that is very accurate, such as by creating a desired fiber alignment in discrete regions of a part, thereby improving the ability to provide molded parts with desired performance characteristics.

Since, in the illustrative embodiment, the preform charge is assembled outside of a mold, it can be readily inspected, such as to ensure proper alignment of the constituent preforms with respect to one another. Furthermore, the preform charge can be sized and shaped to match mold features so that it is necessarily situated and remains in a single, desired position, wherein all fibers in the preform charge are ideally aligned. That is, the preform charge can be naturally “registered” in the mold and held in place therein by virtue of its shape and size. As previously noted, neither such inspection nor registration can be performed for prior-art processes.

Additionally, forming a preform charge at the bending machine, or at an intermediate location between the bending machine and the mold, improves the overall efficiency of the molding process since far fewer trips are required (between the bending machine and the mold) to fill the mold.

It is routine to match the weight of the constituents added to a mold to the desired weight of the final part. To the extent that weight needs to be added/subtracted to meet a target, doing so has been relatively time consuming. In the prior art, such weight adjustment is performed by cutting length from already made sheet-based preforms or adding custom sheet-based preforms to provide additional weight. Due to the variability in preform weight, this requires weighing all of the individual sheet-based preforms before they are placed in the mold. When using a preform charge in accordance with the invention, the weighing process can be automated, and resin or towpreg can be added as necessary to achieve the desired weight. This also represents a time savings over the prior art.

In some embodiments, a preform charge is created using a preform-charge fixture. The fixture enables an accurate and repeatable assembly of preforms, thereby resulting in a preform charge that can then be transferred to a compression molding process. In some embodiments, additional constituents are used in conjunction with the preforms, such as tape, conductive material, etc., to form the preform charge.

The preform-charge fixture is capable of locating and constraining the preforms and any additional constituents in a preferred orientation relative to each other. These constituents are then joined together. In some embodiments, the preform-charge fixture itself is capable of joining the constituents, such as via a heat/energy source and/or an arrangement for compressing the constituents against one another. In some other embodiments, a complementary process, rather than the preform-charge fixture itself, performs the joining/tacking operation. After the preform charge is formed, it is removed from the preform-charge fixture and

placed in a mold and then, under the action of heat and pressure (i.e., compression molding), forms a part.

In some embodiments, the preform-charge fixture includes a plate, an appropriately shaped cavity formed in the plate, clamps, and an energy source. The shape of the cavity situates the constituents (e.g., preforms, etc.) in a desired orientation. Clamps are used, as necessary, to fix the constituents in place and, in some embodiments, to apply some amount of pressure to force the constituents together. The heat/energy source is then used to join the constituents to one another. Preforms can be placed in the cavity by hand or via a robot. In this embodiment, the preform-charge fixture is somewhat analogous to a “mold.”

In some other embodiments, rather than including a cavity, a plate includes a plurality of cleats, which are used to guide and position the constituents of the preform charge into a proper location/orientation. The one or more clamps are then used to fix the constituents in place. The heat/energy source is then used to join the constituents to one another. In this embodiment, the preform-charge fixture is somewhat analogous to a mandrel, wherein the constituents are “wound” around a supporting surface(s).

Important variables of the preform-charge fixture include the geometry of the cavity or the geometry defined by the arrangement of cleats (and location of cleats relative to the clamps), along with the heat/energy source used for joining the constituents. The preform-charge fixture operates in a repeatable, fast, and, in some embodiments, semi- or fully automated manner.

In some embodiments, the present invention provides a method comprising:

- placing a requisite amount of preforms in a preform-charge fixture, each preform consisting essentially of a fiber bundle and resin, wherein the preform-charge fixture creates an assemblage of the preforms, the assemblage having first geometry defined by the preform-charge fixture;

- physically confining, restraining, or applying pressure to the preforms so that the preforms in the assemblage thereof abut one another; and

- softening the preforms when the polymer bundle comprises thermoplastic, thereby causing at least some neighboring preforms in the assemblage to bond to one another to form a preform charge.

In some further embodiments, the present invention provides a method comprising the steps of placing preforms in a fixture, physically confining them, and softening them, as described above, and further comprising:

- placing the preform charge into a mold cavity;

- closing the mold cavity; and

- subjecting the preform charge to elevated temperature and pressure in accordance with compression-molding operational protocols, thereby fabricating a fiber-reinforced composite part.

In some additional embodiments, the present invention provides a method comprising the steps of placing preforms in a fixture, physically confining them, and softening them, as described above, and further comprising:

- weighing the preform charge; and

- when additional weight is required, adding resin or a portion of towpreg to the preform charge, wherein the towpreg has a diameter or length that is less than the diameter of the towpreg used to create each preform.

In yet some other embodiments, the present invention provides a method comprising the steps of placing preforms in a fixture, physically confining them, and softening them, placing the preform charge in a mold cavity, closing the

5

mold, and molding at elevated temperature and pressure, as described above, and further comprising:

inspecting the preform charge via a non-destructive testing method prior to adding the preform charge to the mold cavity.

In some further embodiments, the present invention provides a preform charge, wherein the preform charge comprises an assemblage of preforms, the assemblage having a first geometry, each preform in the assemblage consisting essentially of towpreg, the towpreg including a plurality of fibers and a polymer resin, wherein a sufficient number of preforms in the assemblage are bonded together to ensure that all preforms in the assemblage remain bound thereto.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a method for making a part via a compression molding process using a preform charge in accordance with an illustrative embodiment of the invention.

FIG. 2A depicts a system for making a preform for use in the method of FIG. 1.

FIG. 2B depicts a method for making a preform charge in accordance with the present teachings, for use in the method of FIG. 1.

FIG. 3 depicts sub-operations for use in molding a part in the method of FIG. 1.

FIG. 4 depicts an embodiment of a preform charge, wherein all fiber bundles within the charge are the same length and linear.

FIG. 5 depicts an embodiment of a preform charge, wherein the preform charge includes a weight adjustment.

FIG. 6 depicts an embodiment of a preform charge, wherein fiber bundles have different lengths.

FIG. 7 depicts an embodiment of a preform charge, wherein fiber bundles have different diameters.

FIG. 8 depicts an embodiment of a preform charge, wherein the fiber bundles have a different length and a different alignment.

FIG. 9 depicts an embodiment of a preform charge, wherein an insert is included with the fiber bundles.

FIG. 10 depicts an embodiment of a preform charge, wherein one bundle functions as a stem, being orthogonal and out-of-plane to other fiber bundles.

FIG. 11 depicts an embodiment of a preform-charge fixture suitable for forming preform charges of the type depicted in FIGS. 4-10, wherein the preforms composing the preform charge are arranged in a cavity.

FIG. 12 depicts an embodiment of a preform charge, wherein the fiber bundles are not axially aligned.

FIG. 13 depicts an embodiment of a preform-charge fixture suitable for forming the preform charge of FIG. 12.

FIG. 14 depicts an embodiment of a preform charge, wherein a fiber bundle is bent.

FIG. 15 depicts an embodiment of a preform charge, wherein straight fiber bundles having different orientations are reinforced by curved fiber bundles.

FIG. 16 depicts an embodiment of a preform-charge fixture suitable for forming the preform charge of FIG. 15.

FIG. 17 depicts an embodiment of a preform charge including an interlocking fiber bundle.

FIG. 18 depicts an embodiment of a preform-charge fixture suitable for forming the preform charge of FIG. 17.

FIG. 19 depicts an eleventh embodiment of a preform charge, wherein reinforcing tape is used to help bind the fiber bundles.

6

FIG. 20 depicts an embodiment of a preform charge comprising a rib-and-sheet structure, wherein fiber bundles are arranged into a rectangular form at the perimeter of a sheet.

FIG. 21 depicts a female mold for use in a compression molding process, wherein preforms, preform charges, or both are being placed in a mold to fabricate a part in accordance with the present teachings

#### DETAILED DESCRIPTION

Definitions. The following terms are defined for use in this description and the appended claims:

“Fiber” means an individual strand of material. A fiber has a length that is much greater than its diameter. For use herein, fibers are classified as (i) continuous or (ii) short. Continuous fibers have a length that is about equal to the length of a major feature of a mold in which they are placed. And, similarly, continuous fibers have a length that is about equal to that of the part in which they will reside. Short fibers have a length that is shorter than the length of a major feature of the mold in which they are placed, and typically comparable to the length of minor features of the mold. The term “short fiber,” as used herein, is distinct from the “chopped fiber” or “cut fiber,” as those terms are typically used in the art. In the context of the present disclosure, short fiber is present in a preform and, as such, will have a defined orientation in the preform, the mold, and the final part. As used generally in the art, chopped or cut fiber has a random orientation in a mold and the final part. Additionally, as used herein, the length of “short fiber” will be based on the length of the smaller features of a mold (they will be comparable in length). In contrast, the length of chopped or cut fiber typically bears no predefined relationship to the length of any feature of a mold/part.

“Continuous” fiber or fiber bundles have a length that is about equal to the length of a major feature of a mold in which they are placed (and the final part).

“Short” fiber or fiber bundles have a length that is shorter than the length of a major feature of the mold in which they are placed, and typically comparable to the length of minor features of the mold.

“Tow” means a bundle of fibers (i.e., fiber bundle), and those terms are used interchangeably herein unless otherwise specified. Tows are typically available with fibers numbering in the thousands: a 1K tow, 4K tow, 8K tow, etc.

“Prepreg” means fibers that are impregnated with resin.

“Towpreg” means a fiber bundle (i.e., a tow) that is impregnated with resin.

“Preform” means a sized, or sized and shaped portion of towpreg, wherein the cross section of the towpreg has an aspect ratio (width:thickness) of between about 0.25 to about 6. The term preform explicitly excludes sized/shaped (i) tape (which typically has an aspect ratio—cross section, as above—of between about 10 to about 30), (ii) sheets of fiber, and (iii) laminates.

“Preform Charge” means an assemblage of preforms that are at least loosely bound together so as to maintain their position relative to one another. Preform charges can contain fiber in form factors other than that of fiber bundles, and can contain various inserts, passive or active.

“About” or “Substantially” means +/-20% with respect to a stated figure or nominal value.

Other than in the examples, or where otherwise indicated, all numbers expressing, for example, quantities of ingredients used in the specification and in the claims are to be understood as being modified in all instances by the term “about.” Accordingly, unless indicated to the contrary, the numerical parameters set forth in the following specification and attached claims are understood to be approximations that may vary depending upon the desired properties to be obtained in ways that will be understood by those skilled in the art. Generally, this means a variation of at least +/-15%.

Also, it should be understood that any numerical range recited herein is intended to include all sub-ranges encompassed therein. For example, a range of “1 to 10” is intended to include all sub-ranges between (and including) the recited minimum value of about 1 and the recited maximum value of about 10, that is, having a minimum value equal to or greater than about 1 and a maximum value of equal to or less than about 10.

The towpreg that is sized or sized and shaped to form preforms for use herein includes thousands of individual fibers, typically in multiples of a thousand (e.g., 1 k, 10 k, 24 k, etc.). Although all of the preforms depicted in the Figures are cylindrical (i.e., have a circular cross section), they can have any suitable cross-sectional shape (e.g., oval, trilobal, polygonal, etc.).

The individual fibers in the towpreg/preforms can have any diameter, which is typically, but not necessarily, in a range of 1 to 100 microns. Individual fibers can include an exterior coating such as, without limitation, sizing, to facilitate processing, adhesion of binder, minimize self-adhesion of fibers, or impart certain characteristics (e.g., electrical conductivity, etc.).

Each individual fiber can be formed of a single material or multiple materials (such as from the materials listed below), or can itself be a composite. For example, an individual fiber can comprise a core (of a first material) that is coated with a second material, such as an electrically conductive material, an electrically insulating material, a thermally conductive material, or a thermally insulating material.

In terms of composition, each individual fiber can be, for example and without limitation, carbon, glass, natural fibers, aramid, boron, metal, ceramic, polymer filaments, and others. Non-limiting examples of metal fibers include steel, titanium, tungsten, aluminum, gold, silver, alloys of any of the foregoing, and shape-memory alloys. “Ceramic” refers to all inorganic and non-metallic materials. Non-limiting examples of ceramic fiber include glass (e.g., S-glass, E-glass, AR-glass, etc.), quartz, metal oxide (e.g., alumina), aluminasilicate, calcium silicate, rock wool, boron nitride, silicon carbide, and combinations of any of the foregoing. Furthermore, carbon nanotubes can be used.

Any resin—thermoplastic or thermoset—that bonds to itself under heat and/or pressure can be used. Exemplary thermoplastic resins useful in conjunction with embodiments of the invention include, without limitation, acrylonitrile butadiene styrene (ABS), nylon, polyaryletherketones (PAEK), polybutylene terephthalate (PBT), polycarbonates (PC), and polycarbonate-ABS (PC-ABS), polyetheretherketone (PEEK), polyetherimide (PEI), polyether sulfones (PES), polyethylene (PE), polyethylene terephthalate (PET), polyphenylene sulfide (PPS), polyphenylsulfone (PPSU), polyphosphoric acid (PPA), polypropylene (PP), polysulfone (PSU), polyurethane (PU), polyvinyl chloride (PVC). An exemplary thermoset is epoxy.

A preform charge, as disclosed herein, can consist of as few as two preforms or include as many as are required for

a particular part. A single preform charge can comprise preforms that have fibers and/or resins that are different from one another. It is preferable to have the resin be the same through all preforms in a preform charge, but this is not necessary as long as the different resins are “compatible;” that is, as long as they bond to one another. A preform charge can also include inserts that are not fiber based.

Preforms, Preform Charge, and Part Fabrication

FIG. 1 depicts a block diagram of method **100** for creating a molded part using a preform charge, in accordance with the illustrative embodiment of the invention. In accordance with operation **S101** of method **100**, a preform is created.

FIG. 2A depicts system **200** for creating a preform, as per operation **S101**.

System **200** includes pultruder **202** and preformer **204**. The pultrusion process is used to create a fiber bundle that is impregnated with resin (i.e., towpreg). This process, as performed by a pultruder, is well known in the art (wikipedia.org/wiki/Pultrusion). The feed to pultruder **204** is, for example, pelletized resin and raw fiber (usually provided on spools). If towpreg is available as a feedstock, then the pultruder can be bypassed.

The towpreg, however obtained, is fed to preformer **204**. The preformer comprises one or more devices that are capable of cutting the resin-infused fiber bundle to a size appropriate for use in a specific mold, and, as desired, for bending or otherwise shaping the sized segment of fiber bundle.

Returning now to FIG. 1, after a plurality of preforms are created per operation **S101**, they are used to create a preform charge, per operation **S102**. FIG. 2B depicts a block flow diagram of a method for creating a preform charge.

A preform charge is formed from plural preforms, and is typically created using a preform-charge fixture. The preform-charge fixture, examples of which are depicted in FIGS. 11, 13, 16, and 18 and described later in this specification, is designed to create a preform charge having a specified geometry and size. A number of different preform charges all having a simple geometry with common features may be formed using a single preform-charge fixture. This is the case, for example, for preform charges **400** through **1000** depicted in respective FIGS. 4 through 10, which can all be formed via preform-charge fixture **1140** of FIG. 11. However, as the geometry of a preform charge increases in complexity, such common features are less likely and each such preform charge will then typically require a dedicated preform-charge fixture. It is within the capabilities of those skilled in the art to design, build, and operate a preform-charge fixture to fabricate a preform charge having a specified geometry.

With reference to FIG. 2B, and in accordance with operation **S201**, a preform is placed in a preform-charge fixture. Query, at operation **S202**, whether all required preforms have been placed in the fixture. If “no,” another preform is added to the preform-charge fixture. This process can be performed robotically, wherein after a preform is created per operation **S101**, it is moved, such as via a pick-and-place robot, into/onto the preform-charge fixture. Once the requisite number of preforms have been added to the preform-charge fixture (i.e., “yes” to the query), or as each preform is added, the preform(s) are physically constrained per operation **S203**, such as by clamps.

In embodiments in which the towpreg includes a thermoplastic resin, the constrained preforms are softened, in accordance with operation **S204**, such as via the application of heat, energy, etc. In various embodiments, the heat to bond individual preforms to each other is provided by a hot

plate, a hot implement such as soldering iron, or hot air. Additionally, other methods can be used to bond individual preforms, particularly in situations in which the preforms do not readily bond to one other. Such other methods include, without limitation, ultrasonic welding, friction welding, lasers, heat lamps, chemical adhesives, and mechanical methods such as lashing.

The temperature at which the preforms will soften is a function of the particular thermoplastic resin used. It is within the capabilities of those skilled in the art to determine the temperature at which any given thermoplastic resin will soften. Typically, this temperature is greater than or equal to the heat deflection temperature of the particular thermoplastic. For example, for PA6 (nylon 6), the heat deflection temperature is about 320° F., and this is the temperature at which a PA6-based preform will soften. The force to bond the heated preforms can be gravity (for thermoplastics). For thermosets, or if more force is necessary for thermoplastics, force can be supplied by the end effector on a pick-and-place robot, or clamps. However constrained, the preforms abut one another, and they join/tack to one another (for thermoplastics, the tacking is complete with the removal of heat). This organized assemblage of preforms defines a preform charge.

The station at which preform charges are formed can include a scale to weigh the preform charges and adjust weight, as necessary. In some embodiments, frequency-based non-destructive methods are used to detect fiber breakages, fiber misalignment, cracks, and voids before transferring the preform charge to the mold.

In operation S205, the preform charge is removed from the fixture, such as via a pick-and-place robot.

It is notable that in some embodiments of the invention, the preform charges are assembled via a preform-charge fixture at a location proximal to where the preforms are created. In some other embodiments, the preform charges are formed at a location that is intermediate between the location of preform creation and the mold.

In some embodiments, the preform charge consists of a single, continuous length of prepreg. This may be implemented, for example, via 3D-printing. Using a 3D-printed preform charge may dispense with the need for a separate tacking/bonding operation.

Dimensional accuracy of the preform charge can be important in certain situations. Preform charges can be machined or laser ablated to achieve a predetermined tolerance or to create certain features to mate with other preform charges, preforms, the mold cavity, or the pick-and-place gripper of a robot.

Referring again to method 100 of FIG. 1, after forming one or more preform charges, a part is molded per operation S103. FIG. 3 depicts an embodiment of sub-operations for molding a part.

In accordance with sub-operation S301, one or more preforms, or one or more preform charges, or one or more of both preforms and preform charges, are placed in a mold cavity. In some embodiments, the preform charge may be transferred by a pick-and-place robot directly from the preform-charge fixture to the mold cavity. In some other embodiments, after the preform charge is created, it is robotically transferred to an intermediate holding tray. In such embodiments, the preform charge(s) are transferred from the holding tray to the mold cavity.

The preforms and preform charges are sized and shaped for the geometry of the mold cavity and, typically, to achieve a certain fiber orientation in discrete regions of the part, such as to meet certain performance specifications. The amount of

preforms/preform charges to be added to the mold cavity is based on the anticipated weight of the part being molded, as calculated based on part volume and the density of the molding material (i.e., preforms/preform charges).

Once the requisite amount of preforms and/or preform charges are added to the mold cavity, the mold is closed, per sub-operation S302. In accordance with well known compression molding protocols, heat and pressure is applied and the part is molded.

In some embodiments, an intermediate cavity is used where all preform charges are placed and then consolidated at once by heating the cavity. The intermediate cavity readily disassembles, or the consolidated charge is readily removed, to expose the consolidate preform charge for inspection before it is transferred to a mold cavity.

Exemplary Preform Charges and Fixtures

FIGS. 4-10, 12, 14-15, 17, 19, and 20 depict embodiments of preform charges, each having different architectures. It is to be understood that the number of preforms shown in any particular figure is strictly for illustrative purposes, and that the various architectures of the preform charges are not restricted to any particular number of preforms. That number is dictated, rather, by the size of the mold, among any other considerations.

FIG. 4 depicts preform charge 400 comprising plural—in this embodiment four—preforms 420 that are joined together. Each preform 420 is an appropriately sized segment of towpreg having plural fibers 416 impregnated with resin 418. In this embodiment, each preform 420 in preform charge 400 has the same length, diameter, and orientation.

FIG. 5 depicts preform charge 500, which comprises preform charge 400 of FIG. 4 with weight-adjustment feature 524. It is useful in molding to match the preform weight to the desired weight of the final part, or to sometimes use a predetermined higher weight for overfilling of the mold cavity. Due to the variability in towpreg composition and accuracy in cutting and bending preforms, it is difficult to match weight within a desired tolerance zone by simply counting preforms. In such cases, it is common, in the prior art, to weigh the preforms and then add or subtract weight as necessary by either cutting existing preforms or using custom-cut additional preforms.

In some embodiments, the preform charge is designed to always be no greater than the desired weight. After or during assembly, the preform charge is weighed and, as necessary, weight is added. Weight is added via a nozzle that dispenses a bead of the resin material, or, alternatively, via a separate machine that cuts a requisite amount of towpreg that is smaller in diameter than the preforms of the preform charge and/or has a different length than the preforms in the preform charge, such as weight adjustment towpreg 524. Weight can be subtracted from the preform charge, by, for example, machining or laser ablating.

In some other embodiments, the fiber volume fraction or weight fraction could be measured and adjusted by adding or subtracting (such as via laser ablation) resin from the preform charge. Fiber volume fraction can be measured by various non-destructive methods such as ultrasonic, acoustic, or radiographic.

FIG. 6 depicts preform charge 600 having preforms of different lengths, including relatively longer preforms 620 and relatively shorter preforms 622. This type of preform charge is especially useful for parts having some smaller features, wherein accordance with the method disclosed in applicant's co-pending application Ser. No. 16/509,801, the shorter fibers (from shorter-length preforms) are flowed into the smaller features, and the relatively longer fibers (from

longer-length preforms) do not flow, but rather remain in the main portion of a mold cavity.

FIG. 7 depicts preform charge 700 comprising a first group of preforms having a relatively smaller diameter and a second group of preforms having a relatively larger diameter. In some embodiments, the preforms in the two groups comprise identical material; they simply have a different diameter. This is useful for filling molds or cavities of specific shapes. In addition to including preforms having different diameters in a preform charge, preforms having different cross-sectional shapes can be used to more efficiently fill mold cavities of a specific shape. In some alternative embodiments, the preforms in each group can be made of different materials. For example, in some embodiments, one of the groups comprises carbon fiber and the other group comprises glass fiber, both having the same resin. Preform 700 can have more than two groups of preforms, and/or and a different number of preforms in each group than depicted.

FIG. 8 depicts preform charge 800 having two groups of preforms 820 and 822, wherein the two groups of preforms align with different axes, and have different lengths. In the illustrative embodiment, the axes with which the preforms align are orthogonal to one another. This type of preform charge is particularly useful for plunger-type molds, as disclosed in U.S. Pat. No. 10,946,595. For example, relatively shorter preforms, such as preforms 822, can flow first into the mold to fill smaller features, and relatively longer fiber bundles, such as preforms 820, flow last into the mold to fill large features and connect the smaller features to the larger structure.

FIG. 9 depicts preform charge 900 with preforms 920 and insert 924. In some embodiments, the insert is removable at an appropriate time during the molding process to create an axially aligned through-hole (diamond-shaped in this embodiment) in preform charge 900. In some other embodiments, insert 924 is intended to be non-removable such that it is to be an integral component, such as a sensor, bus, threaded insert, etc., of the final part.

In preform charge 900, insert 924 protrudes beyond the ends of preforms 920. The protruding ends of insert 924 can be used, for example, to register preform charge 900 with features of a mold cavity into which the preform charge is to be placed. In this embodiment, insert 924 is depicted as extending the full length of preform charge 900. In some other embodiments, however, an insert extends only part of the way into the preform charge. In yet some additional embodiments, the insert is completely embedded in the preform charge. Although insert 924 is depicted as being “diamond-shape,” the insert can be of any shape.

FIG. 10 depicts preform charge 1000 having stem 1024. The stem can be another preform of material identical to that of preforms 1020, or it can be resin material only, or a separable part. The stem can be used, for example, to facilitate grabbing a preform charge from the fixture in which it is formed, such as by using a pick-and-place robot. The robot then transfers the preform charge to a mold or, alternatively, to an intermediate holding tray. Stem 1024 is particularly useful for placing preform charges in deep mold cavities. In some embodiments, the stem is part of the preform charge and becomes part of the final part after compression molding. In some other embodiments, stem 1024 is separable and is removed by the pick-and-place robot.

FIG. 11 depicts preform-charge fixture 1130 suitable for forming preform charges of the type depicted in FIGS. 4-10.

Preform-charge fixture 1130 includes plate 1132, cavity 1134, clamp 1136, heat/energy source 1138, interrelated as shown.

In preform-charge fixture 1130, cavity 1134 is formed in plate 1132. The cavity has a simple rectangular geometry, enabling it to be used with a variety of different preform-charges. In the illustrative embodiment, cavity 1134 is being used to create preform 400 depicted in FIG. 4. After all preforms situated in cavity 1134, clamp 1136 drops downward to plate 1132 to apply pressure to the preforms. Heat source 1138, which in this embodiment is a tube that conducts hot air into cavity 1134, is used to soften the preforms so that they can tacked together.

In preform-charge fixture 1130, the function of the cavity (i.e., cavity 1134) is organize the preforms into the orientation/geometry required for creating a desired preform charge. In some other embodiments, that functionality is provided by a plurality of “cleats” and clamps. The arrangement of the cleats is dictated by the geometry of preform charge. Preforms are positioned, either robotically or by hand, against the cleats. The clamps restrain the preforms against the cleats. As with preform-charge fixture 1130, after the preforms are immobilized, they are heated (if the polymer resin is a thermoplastic).

FIG. 12 depicts multi-axial preform charge 1200, wherein two preforms 1220 of identical length cross each other orthogonally. Multi-axial preform charges can consist of any number of preforms, they can cross each other at any angle, and they can cross at any location along the length of the preforms. A multi-axial preform charge, such as preform charge 1200, is useful for creating parts with intersections.

FIG. 13 depicts preform-charge fixture 1330 suitable for forming preform charge 1200 of FIG. 12. Preform-charge fixture 1130 includes the same elements as preform-charge fixture 1130. The only difference is the geometry of cavity 1334 as compared to cavity 1134 of preform-charge fixture 1130.

In preform-charge fixture 1330, cavity 1334 formed in plate 1332 has two cavity portions that cross one another orthogonally and at the midpoint of each cavity portion. Cavity 1334 receives appropriately sized preforms, two of which are depicted positioned over the cavity. After the requisite amount of preforms are added to cavity 1334, clamp 1336 drops downwardly to plate 1332 to apply pressure to the preforms. Heat source 1338, which in this embodiment is a tube that conducts hot air into cavity 1334, is used to soften the preforms for tacking.

FIG. 14 depicts preform charge 1400 with having one straight preform 1420 and one bent preform 1422. Preform charges including bent preforms are used to accommodate specific part patterns and fiber orientations in molds. Bent preforms can be very complex, consisting of several bends in 2D or 3D space. Bent preforms can also function as a registration feature for a preform charge, the one or more bent preforms being used to orient the preform charge within a mold wherein only one such preform charge orientation is possible.

FIG. 15 depicts preform charge 1500 having a multi-axial configuration like preform charge 1200, but also having a reinforced intersection point by virtue of two “u” shaped tows 1522. Such reinforcement improves the properties of the part at the point of intersection of preforms 1520. In some other embodiments, a single “u” shape preform is used for reinforcement, as a function of desired part performance and the part’s loading scenario.

FIG. 16 depicts preform-charge fixture 1630 suitable for forming preform charge 1500 of FIG. 15. Preform-charge

fixture **1630** includes plate **1632**, cavity **1634**, clamps **1636A** and **1636B**, and heat/energy source **1638**, interrelated as shown.

In preform-charge fixture **1630**, cavity **1634** formed in plate **1632** has a geometry suitable for accommodating the preforms the compose preform charge **1500**. Preform-charge fixture **1630** includes two clamps, wherein to ensure that the relatively more complicated arrangement of preforms are appropriately constrained prior for tacking. In this embodiment, heat/energy source **1638** for softening (thermoplastic resin) is a laser.

FIG. **17** depicts preform charge **1700**. In this preform charge, preform **1722** partially wraps around straight preform **1720**. This type of preform charge is used, for example, to increase strength in specific directions within parts.

FIG. **18** depicts preform-charge fixture **1830** suitable for forming preform charge **1700** of FIG. **17**. Preform-charge fixture **1830** includes the same elements as preform-charge fixture **1630**. The only difference is the geometry of cavity **1834** as compared to cavity **1634** of preform-charge fixture **1630**.

To form preform charge **1700**, straight preform **1720** is placed in the appropriate segment of cavity **1834**, followed by bent preform **1722**. Multiple instances of either or both such preforms may, of course, be added to cavity **1834**, as appropriate.

FIG. **19** depicts preform charge **1900**, wherein reinforcing tape **1926** assists in binding preforms **1920**. In preform charge **1900**, the tape is partially wrapped around preforms **1920**. In some other embodiments, the tape fully wraps preforms **1920**. In yet some further embodiments, tape **1926** is wrapped in a helical pattern around and over the length of preforms **1920**. Preform charge **1900** is useful for reinforcing rib-and-sheet structures (see FIG. **20**) or adding strength and stiffness in one or both orthogonal directions to the long axes of the preforms **1920**.

FIG. **20** depicts preform charge **2000** comprising a rib-and-sheet structure, wherein preforms **2020** are arranged into a rectangular form at the perimeter of sheet **2026**. In some embodiments, a single preform **2020** is used to form each "rib." In some alternative embodiments, plural preforms **2020** are used to each rib. Gaps **2028** in the preforms **2020** that form each rib depicts the two end points of the preform. The gaps in one rib are offset from those in the adjacent rib. This results in stronger ribs. Sheet **2026** can be made from unidirectional or woven prepreg tape, a laminate of prepreg tape or sheet, chopped towpreg, metal, plastic, or any combination of the foregoing. Ideally, the resin material of the fiber bundles and the sheet is identical or blend-compatible. The sheet is shown as flat but, in other embodiments, could be a more complicated shape.

The preform charges depicted in the various Figures are representative of a number of geometries that are useful in the creation of parts via compression molding. Such preform charges are presented by way of illustration, not limitation. It is to be understood that there is a practically limitless number of geometries for preform charges, and a nearly limitless number of permutations in terms of the constituent preforms used therein. In light of the present teachings, those skilled in the art will be capable of designing and fabricating preform charges to facilitate the compression molding of any particular part.

Using Preforms and/or Preform Charges in Compression Molding

FIG. **21** depicts female mold **2140** for use in conjunction with a compression-molding process. In some embodiments, female mold **2140** is filled with one or more preform

charges, such as preform charge **2100**, and then subjected to heat and pressure in accordance with compression-molding protocols, well known in the art. In some other embodiments, female mold **2140** is filled with a plurality of preforms, such as preforms **2120**, and then subjected to heat and pressure in accordance with compression molding protocols. And in some yet further embodiments, female mold **2140** is filled with one or more preform charges, such as preform charge **2100**, as well as one more more preforms, such as preforms **2120**.

The selection of preforms only, versus preform charges only, versus both preforms and preform charges for a given mold is a function of the size and shape of the mold cavity, the presence of small features in the mold cavity, and the location and size of discrete regions requiring a particular fiber alignment, among other considerations.

It is to be understood that the disclosure describes a few embodiments and that many variations of the invention can easily be devised by those skilled in the art after reading this disclosure and that the scope of the present invention is to be determined by the following claims.

What is claimed:

1. A method for forming a fiber-composite part, the method comprising:

forming a preform charge using a preform-charge fixture, the preform charge fixture comprising a first cavity, wherein the preform charge is sized and shaped to match a form of a mold cavity of a compression mold, wherein forming the preform charge comprises:

A. stacking, one upon another, a requisite amount of preforms in the first cavity, each preform consisting essentially of a segment of towpreg, the segment of towpreg comprising a bundle of fibers having a cross section of substantially circular or oval shape, wherein the bundle of fibers are impregnated with a polymer resin, the stacking of preforms resulting in an assemblage, the assemblage having a desired fiber alignment and a first geometry dictated by a shape of the first cavity;

B. immobilizing the preforms in the assemblage;

C. after forming the assemblage and immobilizing the preforms therein, softening the preforms, if required due to their chemical composition, thereby causing at least some neighboring preforms in the assemblage to tack together to form the preform charge, while maintaining the desired fiber alignment;

removing the preform charge from the first cavity of the preform charge fixture;

placing the preform charge into the mold cavity of the compression mold, whereby, by virtue of the size and shape of the preform charge, the preform charge registers to the mold cavity;

closing the mold cavity; and

compression molding the preform charge by subjecting the preform charge to elevated temperature and pressure sufficient to fully consolidate the fibers and resin therein, thereby fabricating a fiber-composite part.

2. The method of claim 1 comprising placing plural individual preforms into the mold cavity.

3. The method of claim 1 comprising adding an insert to the assemblage of preforms, wherein the insert creates a through-hole in the fiber-composite part.

4. The method of claim 1 further comprising adding an insert to the assemblage of preforms, wherein the insert remains in the fiber-reinforced composite part.

5. The method of claim 1 wherein, in the first geometry, all preforms in the assemblage have the same length.

15

6. The method of claim 1 and further wherein, in the first geometry, a first preform in the assemblage has a first diameter and a second preform in the assemblage has a second diameter, wherein the first diameter and the second diameter are different from one another.

7. The method of claim 1 and further wherein, in the first geometry, a first preform in the assemblage has a first length and second preform in the assemblage has a second length, wherein the first length and the second length are different from one another.

8. The method of claim 1 and further wherein, in the first geometry, a first preform in the assemblage is parallel to a first direction and a second preform in the assemblage is parallel to a second direction, wherein the first direction and the second direction are different from one another.

9. The method of claim 1 and further wherein, in the first geometry, a first preform in the assemblage is bent, such that a first portion along a length of the first preform aligns with a first direction and a second portion along the length of the first preform aligns with a second direction, wherein the first direction and the second direction are different from one another.

10. The method of claim 1 and further wherein, in the first geometry, a first preform in the assemblage aligns with a first direction, a second preform in the assemblage aligns with a second direction, wherein the first preform and the second preform cross one another at an intersection point, and a third preform that is "u" shaped and which reinforces the intersection point.

11. The method of claim 1 and further wherein, in the first geometry, a first preform in the assemblage is bent, such that

16

a first portion of the first preform has a parallel orientation with respect to a second preform in the assemblage, and a second portion of the first preform has an orthogonal orientation with respect to the second preform, wherein the first preform partially wraps around the second preform such that the first portion and the second portion of the first preform are disposed on opposite sides of the second preform.

12. The method of claim 1 and further wherein, in the first geometry, a segment of tape wraps around the assemblage of preforms.

13. The method of claim 1 and further wherein, in the first geometry, the preforms of the assemblage are arranged into a rectangular shape at a perimeter of a sheet, the first geometry defining a rib-and-sheet structure.

14. The method of claim 1 and further comprising: weighing the preform charge; and when additional weight is required to meet a weight requirement for the fiber-composite part being formed from the preform charge, adding resin or a segment of towpreg to the preform charge, wherein the segment of towpreg has a diameter and/or length that is less than the diameter of the segment of towpreg used to create each preform.

15. The method of claim 1 comprising inspecting the preform charge via a non-destructive testing method prior to adding the preform charge to the mold cavity.

16. The method of claim 1 wherein the size and shape of the preform charge is substantially the same as a size and shape of the mold cavity.

\* \* \* \* \*